
PLEISTOCENE FROST ACTION NEAR THE BORDER OF THE WISCONSIN DRIFT IN PENNSYLVANIA

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The area peripheral to the border of the Wisconsin drift in the Appalachian Plateaus of northcentral Pennsylvania is characterized by an unconsolidated rubble that mantles the landscape from ridge crest to valley bottom. This paper presents the hypothesis that this surficial deposit and the associated landscapes in the periglacial area, or area within a few tens of miles of the Wisconsin drift border, are the result of processes caused by the adjacent Wisconsin ice sheet. In another contribution to this symposium, H. M. Raup describes various phenomena resulting from intense frost action that is characteristic of many parts of arctic and subarctic lands. Soil structures, surficial deposits, and land surfaces found in Potter County and elsewhere in Pennsylvania (figs. 1 and 2) resemble

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those described by Raup from southwestern Yukon and are believed to have had a similar origin.

The topographic development of the Appalachian highlands as pictured in the classical Davisian cycle of erosion proceeded under a "normal" humid temperate climate, and has led to the assumption that the broad, nearly level hilltops have always been the most stable units of the landscape. However, under the hypothesis here presented, the soils on ridge crests near the border of the Wisconsin drift were very unstable during parts of Wisconsin time. The old pre-Wisconsin soils on the uplands that are now preserved only in isolated spots are thought to belong to the Sangamon or last interglacial stage. Therefore it is suggested that these very gently sloping upland surfaces lost most of their ancient soil during Wisconsin time (or possibly in late Sangamon time). Such very gently sloping upland surfaces (slopes of 1° to 5°) are now covered with an unconsolidated mantle of debris that reaches thicknesses of at least 10 feet in places. It is further suggested that this surficial mantle is not forming at the present time but is the result of the breakup of the bedrock by frost action penecontemporaneous with the time when the Wisconsin ice stood at or near its maximum limits in northcentral Pennsylvania. This drift border is believed to be early Wisconsin, possibly Iowan, in age (the "Olean" drift border of MacClintock and Apfel, 1944). The movement of this mantle was due to various causes, the most important of which were solifluction, creep, and running water.

Phenomena indicative of frost action during the Pleistocene have been recognized in Europe for more than three-quarters of a century and have been referred to as periglacial phenomena. An excursion to Spitzbergen in 1910 resulted in a large number of papers by European geologists on frost processes and their products in the Arctic and on the occurrence of frost features of ancient date in the surficial deposits of Europe. Bryan (1928) prepared a review of an extensive work on periglacial phenomena in Europe by Kessler (1925). This review has led to a growing recognition of the importance of frost phenomena for an understanding of the surficial geology of areas near and within the border of the Pleistocene ice sheets.

The literature on the subject of Pleistocene frost action is very extensive. An enlightening summary of the subject together with the extensive bibliography is by H. T. U. Smith (1949b). The March, 1949, number of the *Journal of Geology* (vol. 57, no. 2) is devoted largely to phenomena resulting from frost or periglacial wind action. A recent study by Peltier (1949) deals with similar phenomena in Pennsylvania. Recent work on permafrost or perennially frozen ground especially in Alaska is summarized by Black (1950).

The hypothesis presented here is based on field studies being carried on in Potter County, Pennsylvania, by the U. S. Geological Survey in informal collaboration with the Division of Soil Survey of the U. S. Department of Agriculture and with H. M. Raup and J. C. Goodlett, botanists in Harvard University.

Potter County is near the center of the northern tier of counties along the southern boundary of New York State (fig. 1). The area is in the higher portions of the Appalachian Plateaus and contains the headwaters of the Genesee River that flows northward to Lake Ontario, the Allegheny River that runs westward, and Pine Creek that runs southeastward to the West Branch of the Susquehanna River. The bedrock consists of gently folded sandstone, siltstone, shale, and conglomerate, with very minor amounts of calcareous rock. The regional structure has a northeasterly trend and gives rise to synclinal ridges and anticlinal lowlands with a local relief of 300 to nearly 1000 feet. The highest ridges rise to altitudes of slightly more than 2500 feet. The area is dominantly forested.

About the northern quarter of the county was covered by the Wisconsin ice sheet. The drift border enters the country from the north, near Olean, New York, and has a remarkably straight southeasterly trend across the pronounced ridge and valley topography. The drift border can be rather closely defined as the southern

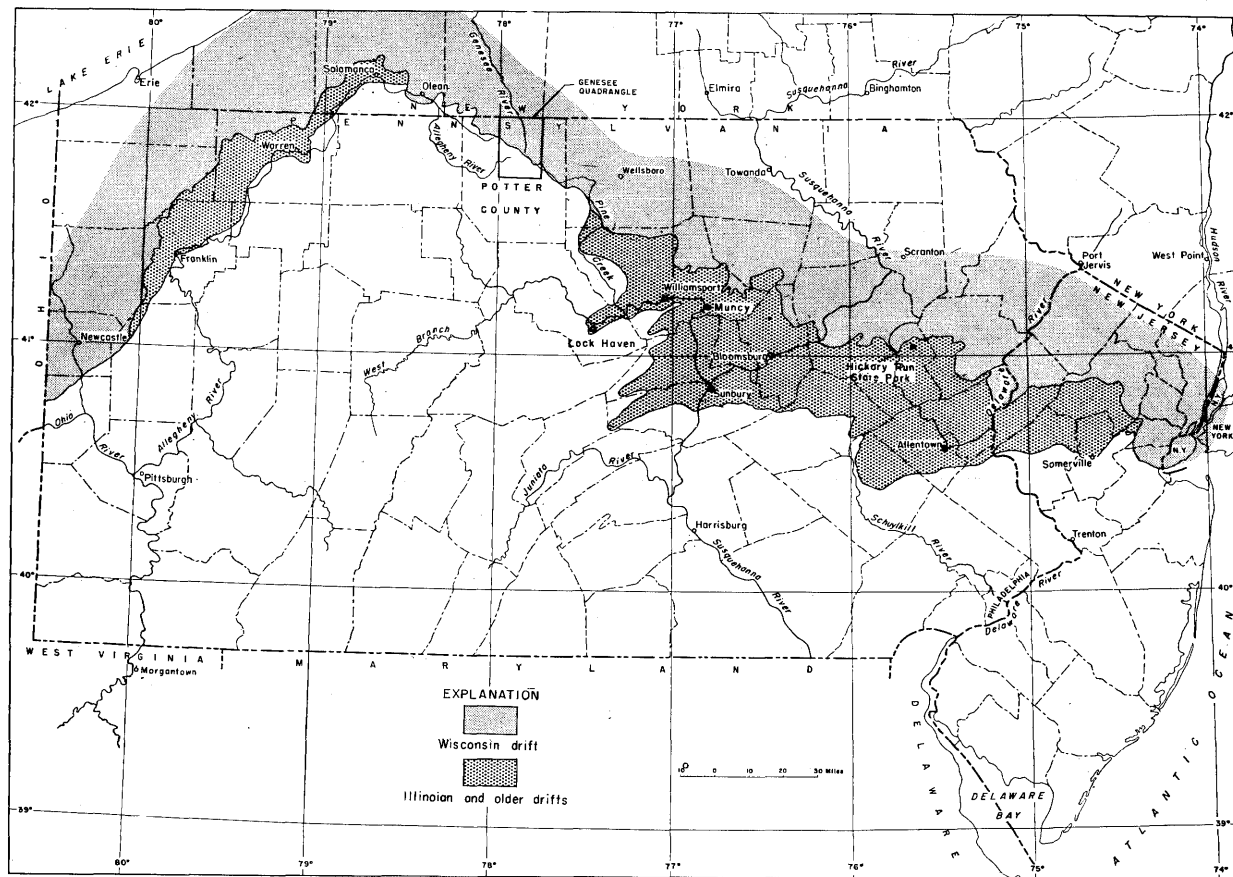


FIGURE 1. Map of glacial deposits in Pennsylvania and adjacent parts of New York and New Jersey. Compiled from Flint and others (1945), Leverett (1934), MacClintock and Apfel (1944), and Salisbury (1902).

limit of erratics of igneous rock or of metamorphic foliates derived either from the Adirondack Mountains or from Canada. There are almost no terminal or recessional moraines and only scanty masses of ground moraine. There are a few small areas of outwash deposits in the form of kame terraces.

SURFACE FEATURES DUE TO FROST ACTION DURING THE WISCONSIN

Blockfields²

Accumulations of large boulders or blocks are found in widely scattered areas near the border of the Wisconsin drift in Pennsylvania. Small blockfields, a few tens to several hundreds of feet in largest dimension, are found in many parts of Potter County and elsewhere. Large blockfields that may be several thousands of feet in length are restricted to areas where the local rock contains beds of massive sandstone or quartzite, as for example, on the mountains south of the West Branch of the Susquehanna River between Muncy and Loch Haven and at the Hickory

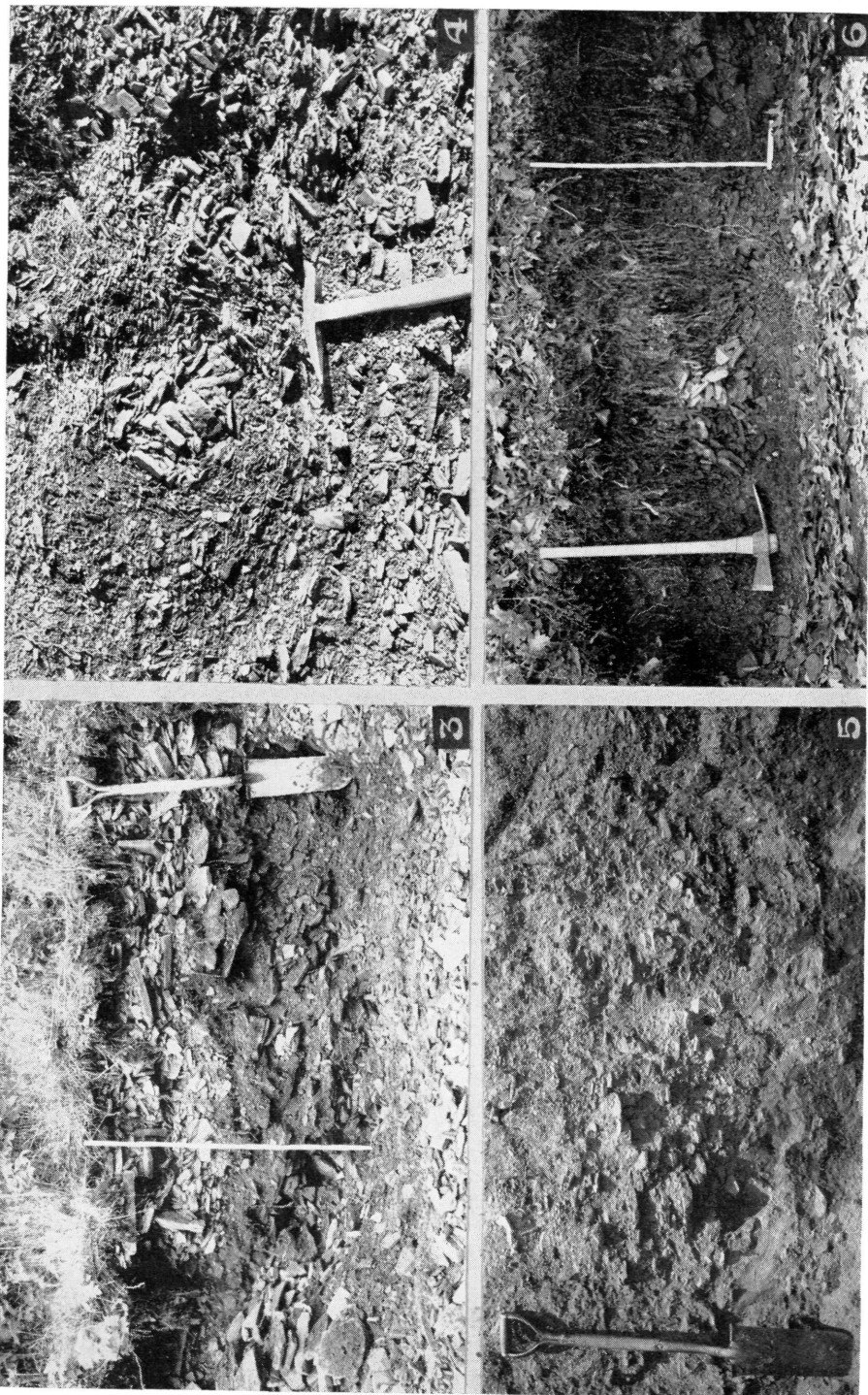


FIGURE 2. Smooth slopes on unconsolidated debris of the Wisconsin stage, from 1 to at least 5 feet thick, developed from shale and sandstone of the Catskill formation. No outcrops of bedrock are visible. Locality is about 6 miles south of the border of the Wisconsin drift. View looking northward from State Highway 144, 0.9 miles west of Germania, Galeton quadrangle, Potter County, Pa.

Run State Park north of Allentown (fig. 1). The blockfields are found on uplands or in shallow valleys where the surface slope is generally only 2° to 5° . The blocks are up to 10 feet in length. Slab-shaped blocks commonly stand with their broad flat surfaces more or less vertical. The individual fragments are covered with lichens and have a weathered rind as much as an inch thick. The blockfields are ancient and do not appear to be forming today. Their antiquity is indicated by the weathered and lichen-covered surface of the individual blocks, the finding of some blocks broken in place into several fragments, the partial covering by vegetation, and their occurrence on very gentle slopes of only 2° to 5° . At only a few localities in Potter County is there positive evidence for present-day movement of individual blocks even on slopes of 25° . This evidence is the disturbance of the surficial organic layer of the soil, either on the forest floor or in the turf of pastures, resulting in breaks in the vegetation on the uphill side of a block or in the formation of a ridge on the downhill side.

The mechanics of formation of blockfields are not clearly understood. There is almost no fine material between the blocks down to depths of 1 to 5 feet. Below that level fine material (generally a silty clay) is present between the blocks. Some workers (Smith, 1949a) argue that a matrix of fine material must have been

²For photographs of blockfields see Smith (1949 a and b).



present between the blocks when they moved. However, in Alaska there are presumably active blockfields in which there is fine material between the boulders at depth, but not within 2 to 4 feet of the surface (D. M. Hopkins, personal communication, December, 1950). The morphological similarity between the blockfields in Pennsylvania and those that are now forming in subarctic and alpine environments leads to the hypothesis that the former are the result of processes active under a cold climate when the surrounding slopes are essentially treeless. It is suggested that such a cold climate was present in the area near the border of the Wisconsin drift at the time when the Wisconsin ice sheet was at or close to its maximum extent.

Surficial deposits outside the border of the Wisconsin drift

The nonglaciated area peripheral to the Wisconsin drift border in Potter County (fig. 1) is characterized by the widespread occurrence of a surficial mangle of unconsolidated debris, largely a rubble. Much of the material is an unsorted, heterogeneous mass that contains from 1 or 2 to almost 100 percent of rock fragments of all sizes from a fraction of an inch to tens of feet in diameter (figs. 3-6). Much of the material on the lower valley walls might be called colluvium. Many of the slab-shaped fragments or flagstones are oriented with their flat surfaces essentially parallel to the slope of the ground. Elsewhere the flagstones may be imbricated with their longest axis dipping toward the top of the slope at angles of a few degrees measured from the ground surface. On ridge tops most rubbles do not show any preferred orientation of the fragments except where the fragments are grouped into circular or linear patterns (boulder rings and boulder stripes). Where the surficial mantle contains considerable fine material and only a subordinate amount of rock fragments, as in areas of fine-grained bedrock such as siltstone or shale, the material resembles till but does not contain erratics or striated rock fragments. The surficial mantle ranges from 1 foot to more than 10 feet in thickness.

It is suggested that this surficial mantle of debris is of Wisconsin age, that it was formed when the ice sheet was at or near the drift border, by processes active in a cold frost climate. On the uplands there is stratigraphic evidence that this mantle has moved down very gentle slopes, 1° to 5° , and in one place accumulated to a thickness of at least 10 feet. The soil profiles developed in the upper part of this mantle suggest that it has been relatively stable for at least 500 to 1000 years. Its degree of weathering is comparable with that on the adjacent Wisconsin drift. The author believes that these deposits can be best explained as the result of processes related to Wisconsin frost action. Most of the deposits on the uplands are probably congeliturbates (Bryan, 1946) or debris produced by frost-riving and

EXPLANATION OF FIGURES

FIGURE 3. Wisconsin colluvium composed of large and small slabs of sandstone with very little matrix and large open voids. Road cut at base of 30° slope on west side of Pine Creek just south of Buckseller Run, Genesee quadrangle, Potter County, Pa.

FIGURE 4. Unconsolidated debris composed of small slabs and chips of sandstone and shale with almost no fines, probably a congeliturbate. Above hammer, fragments show a circular arrangement. Vertical road cut at road corner, about half a mile south of Divide, on southern edge of Laporte quadrangle, Columbia County, Pa.

FIGURE 5. Wisconsin colluvium composed of small slabs of sandstone in a silty matrix. Slabs are rudely imbricated, with their longer axes inclining at a low angle to the left (upslope). Faint irregular stratification visible near base. Exposure in trench that extends upslope across lower end of fanlike deposit. Locality is at mouth of gulch on north side of Allegheny River about 0.4 miles west of Colesburg, Genesee quadrangle, Potter County, Pa.

FIGURE 6. Congeliturbate composed of small slabs and chips of sandstone. Large fragments concentrated in pockets to right of pick and rule. Pockets are cross sections of boulder stripes that extend downslope of 1° or 2° at right angles to exposure. Road bank on north side of State Highway 44 at eastern edge of Oleona quadrangle, Potter County, Pa.

moved by solifluction, the result of a deep seasonal freeze and thaw. The colluvial deposits on the lower slopes are interpreted as the result of a combination of slope wash, creep, and solifluction.

The surficial mantle of unconsolidated debris that essentially conceals the bedrock in areas near the Wisconsin drift border becomes thinner and less continuous as one goes away from the drift border. Likewise there is a change in topography. Slopes in Potter County, for example, have a relatively uniform inclination from top to bottom or become slightly gentler near the base (figs. 2 and 7), and floodplains are essentially absent in headwater areas, the valley walls meeting to form a "V." In contrast in areas farther removed from the Wisconsin drift border the slopes tend to become steeper as one descends, outcrops of bedrock are more abundant, and a narrow floodplain is present even in headwater areas (fig. 7). Such topographic contrasts can be seen in a traverse from Potter County southwestward to Morgantown, West Virginia (fig. 1), or in a traverse from the Wisconsin drift border east of Bloomsburg southwestward for about 75 miles, although in the latter area the presence of scattered patches of pre-Wisconsin drift is a complicating factor. It is suggested that the distribution of this surficial mantle of debris in relation to the Wisconsin drift in Potter County indicates that the two were formed at essentially the same time.

One wonders if the essential absence of gullies on steep cultivated slopes in Potter County as compared with areas more remote from the drift border, such as near Morgantown, is related to the presence of the thick highly permeable rubble in the former area. In Potter County rain water sinks into the ground and emerges as springs near the valley bottom. Near Morgantown, on the other hand, much of the rain water apparently runs off the slope on the ground surface and carves gullies, locally to bedrock.

Boulder rings and boulder stripes³

Many of the surficial deposits of Potter County both within and outside the border of the Wisconsin drift commonly contain a greater abundance of rock fragments at or near the surface than at depth. In many places the fragments form miniature blockfields, surface concentrations of rock fragments from a few inches to 2 or 3 feet in maximum diameter. Locally on slopes of more than 2° these fragments are arranged in stripes or on nearly level surfaces as rings. The bouldery borders are from 2 to 6 feet wide and enclose areas from 4 to 15 feet in diameter with a microrelief of as much as 2 feet. These areas are covered with turf or bushes. Typical boulder rings are most common on poorly drained silty till.

Within the glaciated area the volume of boulders present in any one group of rings is several times greater than that seen in the most bouldery drift in the vicinity. The location of the boulder rings taken in conjunction with what is known of the bedrock indicates that the rings are not related to the outcrop of a given layer of massive sandstone. Boulder rings occur within a few hundred feet of divides and in locations where they cannot be attributed to stream action. Apparently the boulder rings represent a concentration of boulders derived from the reworking of a considerable mass of till. In some places, both within and outside the glaciated area, surficial concentrations of boulders on slopes of 2° to 10° are arranged in roughly parallel stripes. Irregular boulder bands 2 or 3 feet to more than 10 feet wide are separated by relatively stone-free areas 10 to 50 feet wide. Excavations across these stripes show a mass of rock fragments that are packed tightly together and extend to depths of 2 to 3 feet. At comparable depths the material between the stripes is relatively free of rock fragments. Many of the fragments in the stripes are small slabs or flagstones with their broad flat surfaces dipping steeply into the ground and oriented down slope. The boulder

³For photographs of boulder rings and boulder stripes see, for ancient examples, Antevs (1932), Goldthwait (1940), Smith (1949a and b); for modern forms see Antevs (1932), Denny (1940), Rozanski (1943), Sharp (1942), Troll (1944).

stripes are interpreted as the result of the downslope movement of material by solifluction from the surrounding slopes. The boulders move very slowly down the gentle slopes, whereas the finer material (pebbles, sand, silt, and clay) is carried much more rapidly down valley to the principal streams.

The boulders of the rings and stripes are lichen-covered, have weathered rinds as much as 0.25 inch thick, and appear to be similar in general aspect to comparable rock fragments in the weathered zone of the glacial drift in the vicinity.

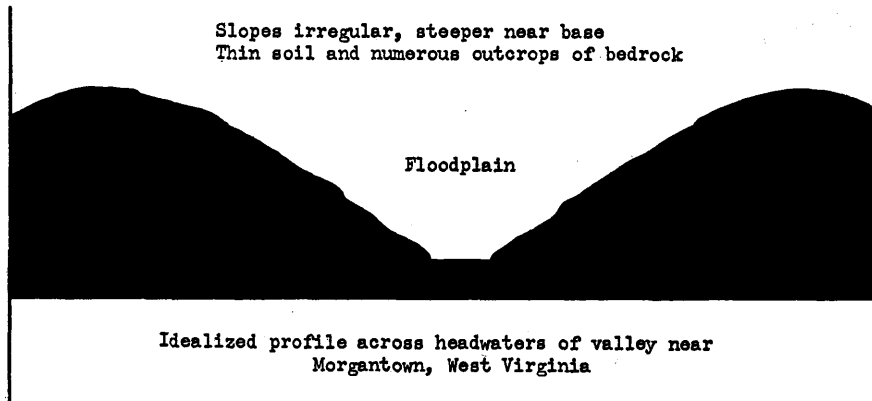
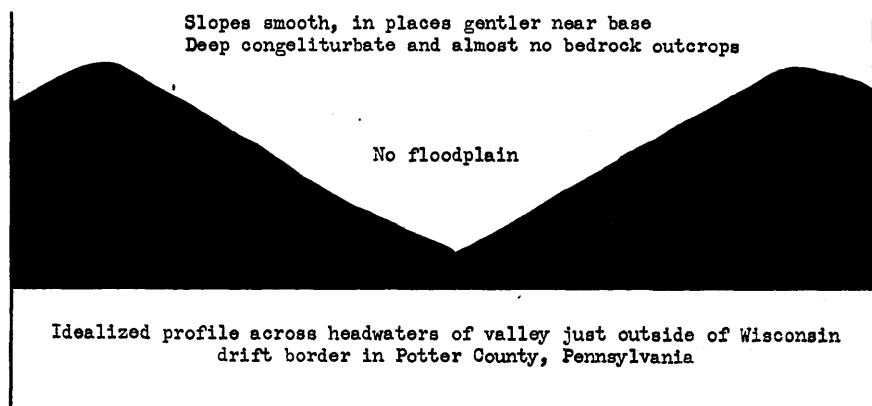


FIGURE 7. Idealized profiles across headwaters of nonglaciaded valleys in Potter County, Pa., and near Morgantown, W. Va.

Many boulders are broken up in place. Several fragments can be fitted together to make a large boulder. All the boulder rings and stripes were forest-covered prior to 1800. The boulder rings are therefore fairly old, probably of early Wisconsin time. Present-day weathering is tending to break up the individual boulders rather than to form new rings.

The morphological similarity between these ancient boulder rings and boulder stripes and those now forming in the subarctic suggests that the two have a common origin. Observations by many workers seem rather definitely to establish the

fact that such soil structures are restricted "to arctic, subarctic, and alpine environments, where the subsoil is for the most part perennially frozen and the surficial layer subjected to repeated freeze and thaw. . . ." (Sharp, 1942). There is as yet not complete agreement as to the actual mechanism involved. Therefore it is suggested that the boulder rings and boulder stripes in Pennsylvania are also the result of a period of deep seasonal freeze and thaw in early Wisconsin time. The boulder rings, stripes, and miniature blockfields are rarely more than one or two boulders deep, a fact suggesting that the assumed freeze and thaw need have extended to only moderate depths, on the order of 10 feet. Perennially frozen ground need not have been present.

CLIMATE AND VEGETATION OF THE PERIGLACIAL AREA

The foregoing hypothesis leads to several tentative conclusions as to the climate and vegetation of the periglacial area. The geographic extent of the surficial mantle of debris suggests that it is related in time and space to the Wisconsin drift in Potter County that is thought to be early Wisconsin, possibly Iowan, in age. The boulder rings, boulder stripes, and blockfields attest to a certain amount of frost action, certainly more than is going on at present. In the absence of any stratigraphic evidence to the contrary it is further suggested that the surficial mantle of debris was formed *pehecontemporaneous* with the above-mentioned soil structures. Therefore it is suggested that both these structures and the associated deposits were formed at a time of more intense frost action. Some of these deposits are interpreted as *congeliturbates* or debris produced and moved by frost action, especially those on gentle slopes of the uplands. Other deposits, notably those on lower slopes near the valley bottoms, suggest a colluvial origin involving transport both by running water and by mass movements. Such data as are available in the vegetation and the soil profiles indicate that this unconsolidated mantle of debris is essentially stable at present. Rarely are slopes gullied; rain water flows through the surficial deposits rather than on top of them. The writer wonders if it is not possible that the erosion of such permeable materials will proceed at a very slow rate until sufficient time has elapsed for the development of a relatively deep soil profile with a B horizon that contains considerably more clay than is present in the modern soil. To produce the movement of such materials on gentle slopes appears to require a deep freezing and thawing of the ground and the lack of a dense forest cover such as was present here prior to 1800. Although it cannot be detailed here, the evidence is good that in favorable localities the present frost climate is sufficient to maintain a miniature blockfield or to produce miniature boulder rings if the vegetative cover is removed.

The boulder rings and boulder stripes suggest that the depth of freeze and thaw was as much as 6 feet. This is the maximum depth at which the base of the soil structures has been observed in places where there has been apparently no burial by later deposits. It is probable that the ground was frozen for several feet below the base of these structures in order to keep the thawed ground saturated with water. If the ground at the base of these structures was not frozen then water from melting ground ice would flow to greater depths and the fine material of the soil structures would dry and be less subject to frost heaving. It is entirely possible that in places the ground remained frozen at depth for many years, that is to say, that there were areas of permafrost (Muller, 1945) or perennially frozen ground. However, none of the periglacial phenomena seen in Pennsylvania to date furnish unequivocal proof of the presence of permafrost. The above-mentioned soil structures can be explained as the result of a deep seasonal freeze and thaw.

Areas in the subarctic or in high mountains where boulder rings, blockfields, and *congeliturbates*, or debris moved by solifluction, are actively forming at the present time are all essentially treeless. In Alaska if trees are present at all they are limited to scattered spruce and poplar (*Populus tacamahaca*) that are inter-

spersed between areas of active blockfields, boulder rings, or boulder stripes (R. S. Sigafoos, personal communication, December, 1950). Observations in the Yukon (Denny and Sticht, 1950) suggest that most congeliturbation and related frost processes take place in areas devoid of forests. By analogy, when such periglacial phenomena were actively forming on the uplands of Pennsylvania those uplands were likewise essentially devoid of forests.

Blockfields and thick surficial deposits resembling those in Potter County are found in the higher parts of the Appalachian highlands as far south as the Great Smoky Mountains. It seems probable that such features are also of Wisconsin age, and may have been formed at a time when the summits of the highlands were essentially treeless.

There is abundant evidence that eolian phenomena, such as loess, sand dunes, and ventifacts, formed by off-ice winds, are associated with areas peripheral to ice sheets. Such features are beyond the scope of this paper.

CONCLUSIONS

The hypothesis is presented that the area peripheral to the Wisconsin ice sheet in northcentral Pennsylvania contains deposits and soil structures that were formed penecontemporaneous with the adjacent early Wisconsin (Iowan?) drift. These features are best explained as due to processes related to more intense frost action than is going on at present at a time when the forest vegetation was greatly restricted. This periglacial area probably had an annual depth of frost penetration somewhat greater than at present, but conclusive proof that the ground was ever perennially frozen is lacking.

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